MORBID INFLUENCES IN INTESTINAL OBSTRUCTION AND STRANGULATION

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INTESTINAL OBSTRUCTION remains one of the most rapidly lethal of surgical diseases. Scudder, Zwemer and Whipple,[29] in 1938, studied a series of 2,150 cases of acute intestinal obstruction and strangulation collected from a number of sources. When herniae and tumors had been excluded from that series, there remained 632 cases, of which 45 per cent had proved fatal. In spite of phenomenal progress in other branches of abdominal surgery, the mortality of acute intestinal obstruction remained at a high, and almost unchanged, level for more than 30 years after the beginning of the present century, and the disease is still a challenge both to the surgeon and to the experimentalist.

The incalculable number of experiments in intestinal obstruction which have been performed during the last quarter of a century have, however, not been fruitless. As a direct result of animal and clinical experimentation, two powerful new weapons have been added to our therapeutic armamentarium—the nasal suction tube and the intravenous saline drip. Powerful as these weapons are, it is wise to realize their limitations. Nasal drainage and intravenous saline are beneficial in most cases of acute intestinal obstruction, and may be continued with benefit for days in simple occlusion of the bowel, for example, and in adynamic ileus. In cases of strangulation, on the other hand, the need for operative relief is much more urgent. It is often difficult to distinguish simple occlusion from strangulation clinically, and to persist with conservative measures in a case of internal strangulation is to court disaster. I have been impressed by more than one case of adhesive obstruction, treated by suction drainage and saline infusion for 24 hours or more, only to present at operation a strangulated and devitalized bowel; 24 hours of delay may mean the difference between viability and gangrene. It is conceivable that, while the present vogue for prolonged preoperative decompression and saline administration may be expected to reduce the mortality of simple intestinal occlusion, it may actually lead to an increase in the mortality of internal strangulation.

Even in simple occlusion of the bowel, patients still die with sufficient frequency to raise the suspicion that we have something yet to learn of the lethal mechanism of the disease. It may be that our administration of saline is too haphazard and inexact; dosage formulae, such as those elaborated in the Department of Surgery of the University of Michigan,[14] certainly merit wider adoption. Whatever the explanation, frequently a patient suffering from intestinal obstruction is lost in spite of preoperative nasal suction drainage, in spite of forced intravenous salines, and in spite of an apparently successful operation. In these fatal cases, the chloride content of the blood may be at or

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near a normal level just before death. One is forced to the conclusion that depletion of water and chlorides is not invariably the sole lethal factor.

In the literature of intestinal obstruction, there is a frequent conflict of theories, and even of experimental observations. This is in great part due to the complexity of the subject. Intestinal obstruction is not a single disease, but a group of diverse diseases; a theory of the cause of death in duodenal occlusion is not applicable to volvulus of the sigmoid colon. It follows, therefore, that each variety of obstruction must be separately studied, and the more exact our pathologic classification is, the more accurate are our observations and deductions likely to be.

The following classification is sufficiently inclusive for clinical purposes, and detailed enough to be a basis for experiment. It must be remembered, however, that pure forms of obstruction, though easily produced in the experimental animal, are relatively rare in clinical practice. In strangulated hernia, for example, the strangulated loop is also a closed loop; the bowel above the strangulation is occluded at the hernial ring, just as in low small intestine obstruction; ultimately, the whole small intestine dilates above the obstruction, and the vomiting of high obstruction is superadded upon the effects of a relatively low obstruction; finally, after relief of the strangulation, the affected loop of bowel may fail to recover its peristalsis, and we may have strangulation, small intestine obstruction, closed loop obstruction, and adynamic ileus all present together in a single case. Of these various forms, one usually predominates, and attracts surgical attention before the other forms have time to exercise their full pathologic effect. In rapidity of effect, strangulation takes precedence over closed loop obstruction, closed loop obstruction over simple occlusion of the lumen, and high occlusion over low occlusion.

CLASSIFICATION OF TYPES OF OBSTRUCTION

A. Simple Occlusion of the Lumen:
   (1) High occlusion of the small intestine.
   (2) Low occlusion of the small intestine.
   (3) Colonic occlusion.

B. Closed Loop Obstruction:
   (1) Sterile loops.
   (2) Heavily infected loops.
   (3) Mildly infected loops.

C. Strangulation:
   (1) Short loops.
   (2) Medium loops.
   (3) Long loops.

A. SIMPLE OCCLUSION

(1) *High Small Intestine Occlusion.*—High small intestine occlusion is the one form of intestinal obstruction in which experimental and clinical study has been completed. In consequence of the work of Maury, Hartwell and Hoguet, Haden and Orr, Elman and Hartmann, Armour, Jenkins, Wangen-

steen, and a host of other workers, it is now recognized that all the phenomena of high small intestine obstruction are dependent upon the loss to the organism of water and of inorganic ions which, poured into the stomach and duodenum in enormous quantities as digestive juice, fail to pass beyond the obstruction to be reabsorbed, as they normally are, by the intestine below. The progressive loss of water leads to an increasing dehydration, which is manifest clinically in the dryness of the patient's skin, the increasing thirst, and the diminution in urinary output. The blood becomes increasingly concentrated, the red cell count and the hemoglobin rise, and there is an increase in blood viscosity and sedimentation rate.

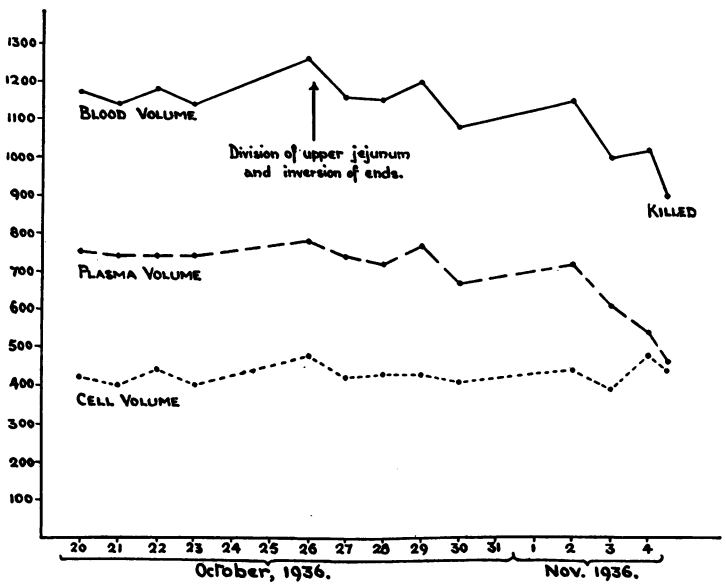


CHART 1.—Showing the terminal depletion of blood volume in an animal subjected to high small intestine occlusion. The reduction in blood volume is wholly due to a fall in plasma volume, the result of dehydration. (By permission of the British Journal of Surgery)

TABLE I

DOGS SUBJECTED TO HIGH SMALL INTESTINE OCCLUSION

The terminal reduction in blood volume is in each case due to a loss of plasma. (By permission of the British Journal of Surgery)

No. of Exper.	Level of Occlusion	Duration of Life	Mean Blood Volume (Cc.)	Reduction in Blood Volume (Per Cent)	Reduction in Plasma Volume (Per Cent)	Reduction in Cell Volume (Per Cent)
1	Terminal duodenum.....	5 days	1,030	25	43	—
2	Below ampulla.....	11 days	1,160	14	33	—
3	Below ampulla.....	6 days	1,360	23	44	7
4	Terminal duodenum.....	13 days	1,400	30	47	—
5	Terminal duodenum.....	9 days	1,180	44	32	—
6	Below ampulla.....	17 days	1,400	18	31	—

These striking effects of high small intestine occlusion may even alter the blood volume, and they alter it in a very characteristic way. Just before death, there is a remarkable reduction (Chart 1) in the volume of circulating blood. If Table I is studied, it will be seen that the terminal declension of the whole blood volume of dogs subjected to occlusion of the duodenum or upper jejunum is determined wholly by a reduction of the volume of the plasma, and that the volume of the red cells remains unaltered. It is profitable to compare this table with the blood volume tables of low small intestine obstruction and of strangulation (Tables IV and VII).

Dehydration is accompanied by demineralization. The chloride content of the blood and tissue fluid falls, and chlorides virtually disappear from the urine. In an attempt to maintain the total electrolyte content of the blood, bicarbonate is withheld in the circulation; the bicarbonate content of the blood is demonstrably elevated, and the carbon dioxide combining-power is increased. Alkalemia is thus established. Meanwhile, as a direct result of the general dehydration, there is an increase in protein catabolism, and, before death, an elevation of the nonprotein nitrogen of the blood. The whole morbid sequence, dehydration, demineralization, alkalemia, azotemia, is too familiar to require further elaboration here, and is fully proved by a mass of clinical and experimental observation.

It is in the treatment of high small intestine occlusion (and in a less degree this applies to pyloric occlusion) that duodenal drainage and the intravenous saline drip have their most dramatic effect. In clinical practice, high small intestine occlusion in its purest form is seen in such conditions as postgastrojejunostomy vomiting, when a loop of jejunum running to or from the stoma becomes kinked, and all the duodenal juices are vomited; or in obstruction of the upper jejunum by bands or adhesions in the upper part of the root of the mesentery. Rarer varieties of obstruction at this level are duodenal ileus, volvulus neonatorum, congenital atresia of the duodenum or duodenojejunal junction, and herniation into the paraduodenal fossae or lesser sac in the upper abdomen.

Most high obstructions are due to simple occlusion of the lumen, and only occasionally does one of the upper loops of small intestine become strangulated. It must, however, be remembered that there are no clinical features to distinguish high occlusion from internal strangulation of one of the upper loops of jejunum. In cases of high intestinal obstruction, there is always a possibility that the obstructed loop is a strangulated loop. In consequence, unless the cause of obstruction is definitely known, and unless strangulation can be definitely excluded, it is unwise to continue duodenal drainage and intravenous saline infusion over too long a period; the restoration of water and chloride should be rapid, for strangulation may be present, and the need for operation is then urgent.

(2) *Low Small Intestine Occlusion.*—This form of obstruction, the commonest clinical variety, has proved a complex problem for both the experimentalist and for the clinician, and it is safe to say that the precise cause of

death is not known. There are a number of factors probably responsible for the deterioration in the patient's condition in most cases, and it is possible that the predominant cause of death may vary from case to case. Most of the available data concerning intestinal obstruction have been obtained from the experimental animal. It should be remembered, however, that the cause of death of an animal suffering from untreated obstruction is not necessarily the same as the cause of death of a patient whose obstruction has been relieved by operation. Our patients suffering from acute obstruction are now invariably treated by operation, and deaths from acute intestinal obstruction now are postoperative deaths. We, of this generation, have virtually no experience of low small intestine obstruction untreated by operation, and our only knowledge of the full, fatal course of the untreated disease is obtained from animal experiment.

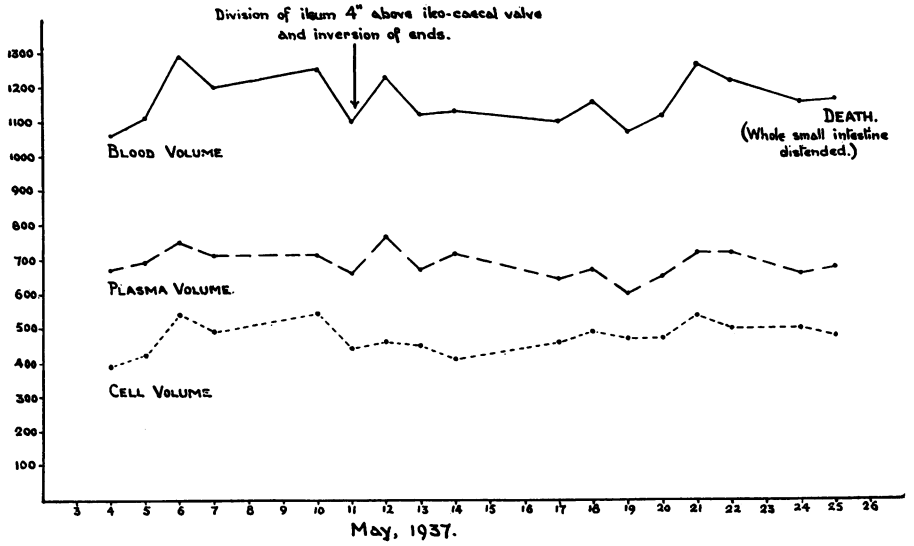


CHART 2.—Low small intestine occlusion in the dog: Showing no reduction in blood volume, plasma volume, or cell volume at the time of death. (By permission of the British Journal of Surgery)

During the last century, before operative relief became the standard treatment of acute intestinal obstruction, the patient suffering from acute, low small intestine occlusion died, as a rule, toward the end of the third, or during the fourth week of his illness. The duration of life then was the same as it is in the untreated experimental animal to-day. Even the patient suffering from internal strangulation lived into the second or third week after the appearance of symptoms. To-day, the sufferer from low obstruction comes under the surgeon's care after a few days or, at most, a week of illness; his obstruction is relieved, and, if he dies, he dies within 24 to 48 hours postoperative. Fatal cases die sooner after the onset of obstruction to-day than they did a century ago.

The treated and the untreated cases of intestinal obstruction present sep-

arate problems, and require separate methods of study. The cause of death in unrelieved cases will be discussed first, and the cause of death in the case which is submitted to operation will be considered subsequently.

I. *Unrelieved Small Intestine Occlusion.*—The animal or man suffering from untreated low small intestine occlusion lives for a period of three or four weeks, during which a number of separate factors combine to produce a gradual deterioration in his general condition and vitality. Each of these morbid factors will be dealt with in turn.

Salt and Water Loss.—In obstruction of the lower ileum, the loss of water and chlorides, while perhaps important in many cases, cannot be held wholly responsible for death. Even in the late stages of the disease, dehydration is often relatively slight (Chart 2), and it is rare to find a reduction of more than 25 per cent in the blood chlorides. In occlusion at higher levels, where chloride loss is the main or sole cause of death, the blood chlorides often reach an agonal level of 50 per cent. Many cases of low small intestine obstruction—the majority of them in my experience—die with no great alteration in the chloride content of the blood, without a high degree of alkalemia, and with little, if any, elevation in the nonprotein nitrogen of the blood. In some cases, no change whatever is demonstrable in the blood chemistry.

Certain cases of low small intestine occlusion do, of course, present a considerable water and salt loss. Vomiting is relatively late, but, above the obstruction, intestinal juices accumulate in the loops of bowel, and distend them so that the veins in the bowel wall are congested, the mucosa becomes edematous, and there is a progressive increase in the secretion of juice from the intestinal glands. Water and electrolytes, accumulating in the lumen of the bowel, are lost to the organism just as surely as if they were immediately vomited. In such cases as these, dehydration and chloride depletion require treatment, and they perhaps play some part in the so-called "toxemia" of obstruction. Yet administration of water and chlorides does not greatly prolong the life of a man or of an animal suffering from unrelieved simple occlusion of the lower ileum.

The duodenal tube, too, invaluable in high intestinal occlusion, has some application in the treatment of low occlusion. Through a nasal suction tube, the duodenal juices may be withdrawn, and may so be prevented from descending into the distended lower loops of bowel and adding to the stagnant intestinal content. The most distended loops of bowel, however, are those which lie immediately above the obstructing agent, and it is difficult, in most cases, to decompress these lower loops satisfactorily by way of a duodenal tube. These lower distended loops appear to be in themselves mainly responsible for the so-called "toxemia" of low small intestine occlusion, and their distention may cause death long before the loss of fluid and salt into them has given rise to any degree of dehydration or hypochloremia. The cause of death in low small intestine obstruction must be sought in the distended bowel loops.

Perforation and Peritonitis.—In the experimental animal, the course of a

low small intestine occlusion is frequently terminated by a perforation of the distended bowel, and peritonitis. This cause of death is not commonly seen now in man, since the patient comes to operation, in the vast majority of cases, before perforation occurs. Reference to any text-book of surgery written during the last century will convince the reader that perforation of the ileum from a stercoral ulcer was relatively common as a terminal event in unrelieved low small intestine occlusion then, just as it is to-day in the experimental animal.[32]

Reflex Nervous Causes.—It has been contended that reflex depression of the circulation by sensory impulses from the distended bowel plays an important part in low intestinal obstruction, but until recently there has been little evidence in favor of this theory. Herrin and Meek[18] succeeded in establishing a distention of bowel without any occlusion of the gastro-intestinal lumen. They isolated a bowel loop and reconstituted the lumen of the intestine around it. The isolated loop was then anastomosed to the reconstituted bowel on the one hand, and brought out on the skin surface on the other. (The fistula produced in this way is known as a Thiry-Vella fistula.) Into this isolated loop a balloon was inserted and inflated. The balloon distended that part of the loop in which it lay, but the bowel on each side of the balloon drained satisfactorily, either into the main intestinal canal or on to the skin surface. Balloon distention of this kind was found by Herrin and Meek to be rapidly fatal, producing a serious diminution of the blood chlorides and elevation of the nonprotein nitrogen. This effect of distention on the blood chemistry Herrin and Meek believe to be due to a reflex hypersecretion of intestinal juice. Denervation of the distended loop permitted the animal to live almost indefinitely. These experiments were repeated by Taylor, Welch, and Harrison,[31] who confirmed the fatal effect of balloon distention of a Thiry-Vella loop, but were not successful in prolonging life by denervation of the distended bowel.

In several experiments, I have maintained balloon distention of Thiry-Vella fistula loops, and have not found that distention, in itself, is necessarily fatal. In one animal, a balloon inserted into a Thiry-Vella loop was maintained at a high state of tension by repeated inflation, yet the animal continued to live, without serious symptoms, for 35 days, when it was sacrificed. During this whole period, the balloon within the fistulous loop was palpable as an abdominal tumor, yet no serious symptoms arose. This single experiment is almost sufficient in itself to suggest that afferent impulses from the obstructed bowel have little, if anything, to do with the so-called "toxemia" of low obstruction.

Splanchnic Congestion.—Loss of blood and plasma into the wall of the distended, congested bowel above a simple occlusion has been said to occasion a depletion of the circulating blood volume, and has been blamed for death in cases of low occlusion. The evidence upon which this theory rests is to be found only in groups of experiments in which the wall of obstructed bowel is weighed, and the amount of fluid and blood lying in it estimated. Actually,

even by this method, when the distended portion of the intestine above the occlusion is compared in weight with collapsed bowel below, the gain in weight of the distended loop from the blood in its congested vessels and the plasma in its edematous wall is relatively small when expressed as a percentage of the blood volume.

TABLE II

LOSS OF EFFECTIVE CIRCULATING BLOOD VOLUME IN SIMPLE LOW SMALL INTESTINE OCCLUSION

Degree of splanchnic congestion measured by a comparison of the weights of loops of equal length taken from above and from below the occlusion after death. (By permission of the Edinburgh Medical Journal)

	Fraction of Intestine Isolated as Closed Loop	Duration of Life	Weight of Closed Loop (Gm.)	Weight of Healthy Loop of Equal Length (Gm.)	Gain in Weight of Closed Loop (Gm.)	Weight of Animal (Gm.)	Blood Volume (approx.) (Cc.)	Loss of Edema Fluid and Blood Expressed as Percentage of Blood Volume
1	One-half....	2 days	48.0	23.0	25.0	3,100	233	11.0
2	One-quarter.	6 days	14.3	9.8	4.5	2,900	218	1.6
3	One-fifth ...	4 days	13.3	10.9	2.4	2,600	195	1.3
4	One-fifth....	4 days	11.1	7.8	3.5	2,400	180	1.8
5	One-fifth ...	3 days	10.9	7.4	3.5	1,900	143	2.5
6	One-seventh	4 days	11.7	7.0	4.7	2,400	185	3.0
7	One-tenth ..	5 days	12.3	8.4	3.9	2,700	203	1.9

TABLE III

LOOPS OF SMALL INTESTINE OF CATS ISOLATED BY DOUBLE LIGATION AND INVAGINATION, AND PERMITTED TO DISTEND AS CLOSED LOOPS

Lengths of bowel equal in length to the closed loops were marked off at the time of establishment of the obstruction by seromuscular stitches of silk; and after the death of the animal were compared in weight with the closed loops. A simple occlusion of the lumen was avoided in these animals by short-circuiting the small intestine around the closed loop.

	Fraction of Small Intestine Distended	Weight of Distended Loop (Gm.)	Weight of Healthy Loop of Equal Length (Gm.)	Weight of Plasma and Blood Lost into Bowel Wall (Gm.)	Estimated Blood Volume (Cc.)	Blood and Plasma Excess in Bowel Wall Expressed as Percentage of Blood Volume
1	One-half.....	105.0	24.0	81	233	34
2	One-half.....	85.0	21.0	64	172	37
3	One-quarter.....	47.4	11.4	36	210	17
4	One-quarter.....	41.0	14.0	27	225	12
5	One-eighth.....	23.5	8.5	15	165	10

In Table II, it will be seen that if an occlusion is established in the middle of the small intestine, the sum of edema-fluid and blood lost into the upper distended half above the obstruction amounts to only 11 per cent of the blood volume. The whole length of small intestine similarly distended would pre-

sumably accommodate a volume of edema-fluid and blood equivalent to little over 20 per cent of the blood volume. Even if this loss were of whole blood, it would be comparable with the blood lost in a considerable, but certainly not in a serious, hemorrhage. The theory of splanchnic congestion, however, has gained so much support, and the measurement of blood lost by the weighing of distended bowel loops is admittedly so inaccurate, that it was felt necessary to estimate directly the effect of splanchnic congestion on the blood volume. In a series of animals, the blood volume was measured on several occasions before the establishment of low occlusion, and at repeated intervals in the survival period after the operation had been performed. Illustrative results are shown in Table IV. Most of the animals died with no alteration whatever in the volume of the whole blood or plasma, and even when death was obviously impending there was no such reduction in blood volume as occurs in extensive strangulation, for example, or in high small intestine obstruction. For this reason, I believe that the loss of blood and plasma into the congested and edematous wall of the obstructed bowel is not the main cause of death in low small intestine occlusion.

TABLE IV

ILLUSTRATIVE DATA FROM DOGS SUBJECTED TO LOW SMALL INTESTINE OCCLUSION

In Dogs Nos. 1 and 4 death has occurred with no reduction whatever in blood volume. In Dogs Nos. 2 and 3 there is a considerable reduction in blood volume, in plasma volume, and in cell volume. In these animals, the small intestine was distended to the point of nonviability—a degree of distention-congestion rarely seen in man. (By permission of the British Journal of Surgery)

No. of Exper.	Level of Occlusion	Duration of Life	Mean Blood Volume (Cc.)	Reduction in Blood Volume (Per Cent)	Reduction in Plasma Volume (Per Cent)	Reduction in Cell Volume (Per Cent)
1	Lower ileum.....	14 days	1,170	—	—	—
2	Lower ileum.....	7 days	2,020	23	31	20
3	Lower ileum.....	9 days	1,610	44	50	37
4	Lower ileum.....	9 days	1,410	—	—	—

It is necessary to add, however, that in a certain proportion of animals the blood volume is to some extent depleted before death, and that the depletion affects both plasma volume and cell volume. This occurs only when intestinal distention is extreme, and when the congestion of the bowel wall is so great above the obstruction as to suggest incipient devitalization. Such a marked engorgement of obstructed intestine, frequently seen in the laboratory animal suffering from intestinal occlusion, does not commonly occur now in man. In the untreated case before the days of modern surgery, however, it would appear from the literature that gross congestion of the bowel was common at the time of death, and a considerable blood loss may have been present in these cases, just as it now is sometimes in the experimental animal.

Potassium Poisoning.—Scudder and his coworkers[29] have blamed potassium poisoning for the lethal effects of intestinal obstruction. They have shown that in a certain number of cases the potassium content of the blood is

elevated both in clinical and in experimental cases of intestinal occlusion. Scudder suggests that the elevation of blood potassium is associated with adrenal insufficiency, and recalls that Wohl *et al.*,[37] examining the adrenal glands in obstructed animals, found a depletion of the cells of the cortex. It should be observed, however, that in only seven out of 20 of Scudder's cases was the plasma potassium elevated, and in only five instances was the blood potassium raised. Elevation of potassium, therefore, does not seem to be an essential factor in intestinal obstruction. Scudder found the blood potassium more altered in cases of high occlusion than in cases of low occlusion, and it is noteworthy that Wohl *et al.* observed cortical depletion only in those dogs suffering from intestinal obstruction which were not treated by saline. Saline treatment seems to prevent adrenocortical depletion. It seems possible, therefore, that the alteration in the adrenal glands and in the potassium metabolism may be a function of chloride loss.

It has been shown that adrenocortical extract may be given with benefit in cases of intestinal obstruction, but this is in itself no proof of adrenal deficiency. The beneficent effect of cortical extract may be due purely to the mobilization of chloride which it occasions. It certainly appears to be most effective in cases of high small intestine obstruction where the blood chloride is low.

Toxemia.—From time to time, various toxic theories have been elaborated to explain the lethal effects of intestinal obstruction, the most recent proponent of the toxemia theory being M. J. Bottin,[12] of Liége, who suggests a toxemia of pancreatic origin to explain not only ileal obstruction, but high small intestine obstruction as well. It has never, however, been shown by injection methods that any toxins circulate in the blood of men or of animals suffering from intestinal obstruction, nor, indeed, is this theory of toxemia supported by cross-circulation experiments. This negative statement is no proof, of course, that toxemia does not occur. In an animal suffering from such a definite toxemia as diphtheria or strychnine poisoning, for example, it is difficult to prove, by injecting that animal's blood into another animal of the same size, that the blood has toxic properties. The apparent absence of toxic properties from small quantities, or even large quantities, of blood is no evidence of the absence of toxemia.

There is, however, one important argument against the presence of a toxemia in the patient, or animal, who suffers from intestinal obstruction. That argument is that all absorption is retarded in distended bowel loops. There is no question that many chemical and bacterial toxins are present in the lumen of an obstructed bowel, just as they are present in the lumen of a normal bowel, but in neither case does absorption of that toxic material appear to occur.

Let me recall an important classic experiment of Braun and Boruttau which demonstrates how much absorption is lessened in a distended bowel loop. If, in an experimental animal, a bowel loop is isolated and distended with saline until congestion occurs in the wall of the loop, a fatal dose of strychnine injected into the lumen of the distended loop does not produce any

symptoms of strychnine poisoning. The strychnine has failed to pass from the lumen of the distended loop into the blood stream. A similar retardation of absorption has been shown for electrolytes and for certain dyes.[11, 13, 22] So, in intestinal obstruction, it seems unlikely that there is a passage of toxin from the lumen of the distended bowel to the blood stream.

It might be argued that, though direct absorption from the lumen of the bowel to the blood stream is delayed in the presence of intestinal distention, lymphatic absorption from the distended bowel is accelerated by the congestion which occurs in its wall. Wangensteen[34] has shown experimentally, however, that ligation or division of the lymphatic pedicle draining a distended bowel loop does nothing to prolong life.

Starvation and Alimentary Depletion.—This factor in the morbidity of intestinal obstruction has received insufficient attention. The patient who presents nowadays with low small intestine occlusion has been ill for only a few days, as a rule, and a few days' starvation cannot be responsible then for a fatal issue, though it should be remembered that even a day or two of starvation exaggerates the general effect of any form of trauma or disease. Previously, however, when the patient lived untreated for three weeks or more after the onset of obstruction, starvation must have been an important factor, just as it is, no doubt, in the experimental animal suffering from low small intestine occlusion to-day. In the presence of acute obstruction, the patient or animal, as a rule, refuses food, but even if food materials are ingested they are not absorbed. The intestine above the obstruction is distended, circulation is enormously slowed in the bowel wall, and the main function of the intestine, that of absorption, has come to a standstill. Not only the water and chloride content of the intestinal juice, but the products of digestion, the cholalic acid, the glycine and the taurine of the bile salts, the lipoids (cholesterol and lecithin) of the bile, failed to reach the circulation. The steady loss of these substances over a period of two or three weeks amounts to a serious alimentary depletion.

We have attempted, in the experimental animal, to overcome the factor of alimentary depletion by the intravenous administration of chyle. B. M. Dick[15] first suggested that chyle might prove a suitable food material for intravenous injection in marasmus and other forms of cachexia, and his suggestion has been applied to the treatment of dogs suffering from intestinal obstruction. Large quantities of chyle were collected, and were injected intravenously into obstructed animals.

Technic of Collection of Chyle for Intravenous Administration to an Obstructed Animal.—The difficulty in these experiments was to obtain a sufficient quantity of sterile chyle. It was considered that, by the production of chylothorax in healthy animals, reservoirs of chyle might be obtained, to be tapped at convenient times by paracentesis thoracis. Chylothorax, however, is difficult to produce experimentally. Mouchet[25] succeeded in obtaining chylothorax only twice in a long series of animals, by the establishment of a simple fistula between thoracic duct and pleural cavity, and even in these two cases the chylothorax was transitory.

In our earlier experiments, it was found that if the thoracic duct is merely

divided and its lower end transplanted into the pleural cavity, the communication between duct and pleura rapidly closes. Apparently, after division of the thoracic duct, other anastomotic lymphatic channels open, and a new route is established for the passage of chyle from the abdomen to the great veins of the neck. It was felt that, in addition to an anastomosis between thoracic duct and pleura, some means must be found of preventing chyle from reaching the great veins by alternative routes. The simplest method of interfering with the drainage of chyle into the veins of the neck appeared to be by the ligation of the superior vena cava. Ligation of the left innominate vein did not suffice to produce an actual stasis, since, in the dog at least, there appears to be a subsidiary route for chyle by way of the right lymph duct to the right innominate vein. The following method was, therefore, elaborated. The right pleural cavity was opened, and the thoracic duct identified in the lower mediastinum. The mediastinal pleura was then torn through with an aneurysm needle, and the thoracic duct cut across. The superior vena cava was then ligated in the upper part of the mediastinum, and the vena azygos was also ligated toward its termination. After this operation, a chylothorax developed on the right side in nearly every case. The pleural cavity was tapped daily after the operation. On the first few occasions, a thin, blood stained fluid was withdrawn, but, later, white, milky chyle was obtained. Sometimes as much as 500 cc. of chyle was obtained daily from the larger dogs. The chyle obtained in this way clotted soon after withdrawal if left at room temperature, and the addition of citrate did not, of course, prevent coagulation. It was found, however, that if the chyle was placed in a refrigerator immediately after withdrawal, coagulation was largely avoided. Our routine practice, therefore, was either to inject the chyle obtained immediately, or, better, to leave the chyle at a refrigerator temperature of 1° or 2° F. for a day or two. Before injection, any coagulum was removed by filtration.

In this way, a constant reservoir of chyle was available. A number of animals were subjected to low small intestine occlusion, and were treated by the daily intravenous injection of chyle. It was found that in no case did the chyle exercise an obvious toxic effect. The average daily dose of chyle was arbitrarily fixed at 30 per cent of the estimated blood volume of the recipient dog. Five dogs were treated in this way. One of these died after a period of ten days. Two other dogs lived for a period of three weeks. One dog lived until the thirty-first day, and in the fifth animal, death was postponed till the thirty-fifth day. All five animals died of perforation of the small intestine, and peritonitis. The statistics in this series are not, of course, conclusive; suggestive as they are, they are best left without comment. They perhaps indicate, however, that the transfusion of chyle as a treatment of alimentary depletion and starvation might prove a fruitful field for investigation.

II. *The Cause of Death in Cases of Low Small Intestine Occlusion after Operative Relief of the Obstruction.*—It has already been mentioned that no definite toxemia has ever been proved to be present during the actual presence of an abdominal distention or obstruction. There is, however, some evidence

that a toxemia may result from the sudden deflation of distended bowel loops. We are all familiar with the clinical case of intestinal obstruction in which the patient is admitted to hospital relatively early in the disease, with a considerable abdominal distention, but yet in a fairly good general condition. Operation is performed, and the obstruction is successfully relieved. After operation, the abdomen loses its distention to some extent, yet the patient gradually sinks into a listless apathy, the pulse rate rises, the blood pressure falls, and in an hour or two, or in a day or two, the patient dies. The patients who die from intestinal obstruction nowadays die, as a rule, after an operation has been performed.

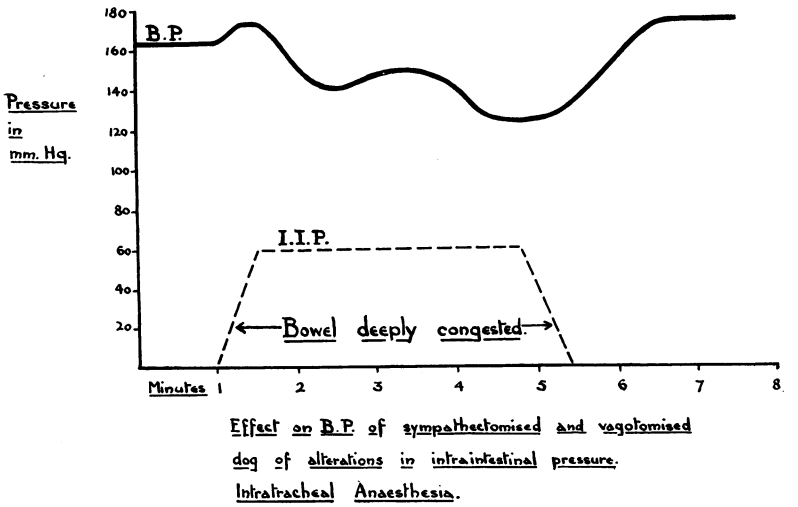


CHART 3.—Demonstrating that induction of distention and congestion of small intestine causes a fall in systolic pressure, apparently the result of splanchnic congestion. Relief of distention and congestion after a few minutes is followed by elevation of systolic pressure, as a result of the return of blood from the congested bowel to the general circulation. (Cf. Charts 4, 5 and 6.)

The same phenomenon is seen clinically in an even more extreme degree in cases where a strangulation is relieved by operation, and it is seen in its most characteristic form after reduction of an intussusception. There are cases of intussusception in which, at operation, the intussusception is reduced, and the intussusceptum, obviously still viable, is returned to the abdomen; after operation, within 24 hours, as a rule, the temperature and the pulse rate rise, the systolic blood pressure falls, the patient becomes pale, sometimes listless, sometimes excited, and death may occur. This alarming phenomenon sometimes happens rapidly, and it may even occur on the operating table. It is notorious that the postoperative course of an intussusception is likely to be more serious if the invagination is difficult to reduce, and if the intussusceptum has to be forcibly squeezed out from its sheath by a long-continued manipulation.

The rapid and lethal depression of the systolic blood pressure which may

follow relief of an intestinal obstruction was seen with greater frequency in former times, when attempts were made by aspiration of distended bowel loops to empty these loops rapidly at operation, and when it was customary to milk down distended bowel at operation, to evacuate it. Let us examine whether the postoperative deaths in intestinal obstruction are due simply to the

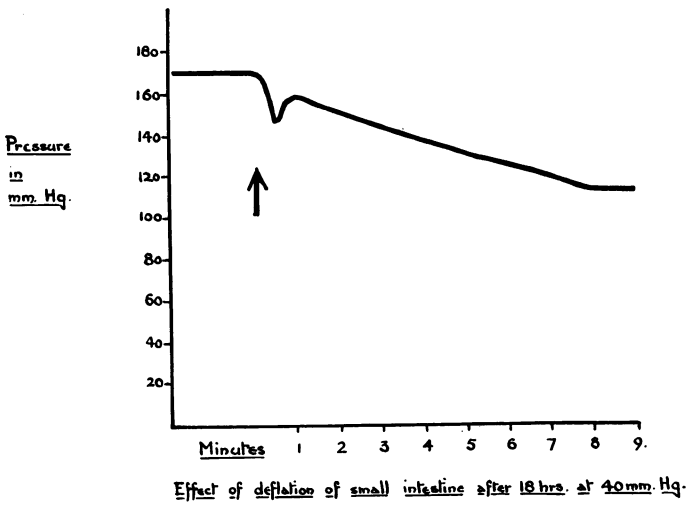


CHART 4.

CHARTS 4, 5 and 6.—Demonstrating that release of a long-continued distention-congestion of bowel in the dog is followed by a serious, and sometimes fatal, depression of the systolic pressure.

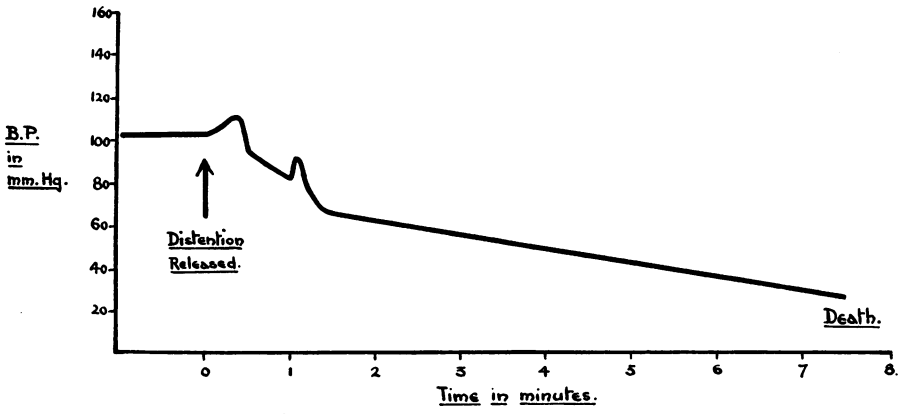


CHART 5.

shock of an abdominal operation performed upon a seriously ill patient, or whether there is a specific depressor factor in the actual release of obstruction.

It has been possible, experimentally, to produce a depressor effect in ani-

mals by the sudden relief of intestinal distention.[2, 3, 4] If the whole small intestine of an animal is rapidly inflated to the point of cyanosis, there is a sudden depression of the systolic blood pressure. This appears to be due to the loss of effective circulating blood into the distended vessels of the inflated bowel, and is an effect of splanchnic congestion; after its initial depression, the blood pressure usually rises again quite rapidly to normal. If the distended bowel is suddenly collapsed soon after its inflation, its congestion quickly disappears, its engorged veins empty, there is an increased blood return to the heart, an augmentation of the circulating blood volume, and a transient rise in blood pressure (Chart 3). If, however, the intestinal distention is maintained for a long period, and is then rapidly released, there occurs, not an elevation, but a depression of the blood pressure (Charts 4, 5, 6 and Table V).

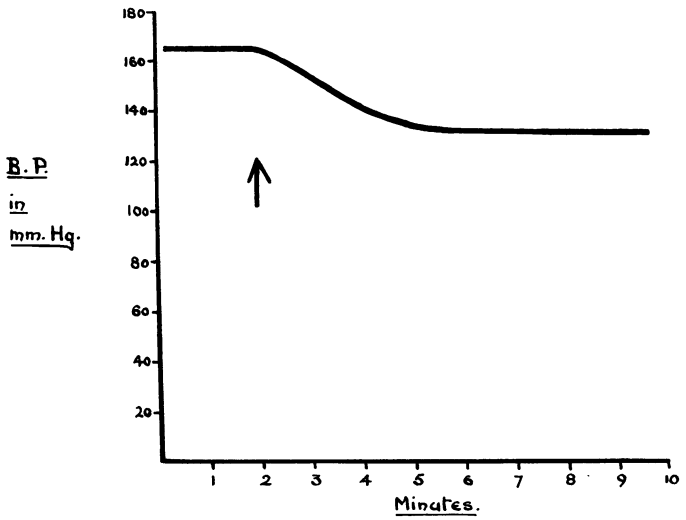
TABLE V

EXPERIMENTS SHOWING EFFECT OF RELEASE OF DISTENTION-CONGESTION OF BOWEL

Early relief leads to increased return of venous blood from congested bowel to heart. Systolic pressure rises (protocols Nos. 1 to 9). The delayed relief of long-continued distention-congestion is followed by improvement in color of bowel, presumably by increased blood return to the heart, but by a depression instead of an elevation of the systolic pressure. This suggests the return of a depressor substance to the general circulation from the previously obstructed intestine (Exper. Nos. 10 to 14).

No. of Exper.	Intra-intestinal Pressure Induced	Animal	Afferent Paths from Heart Interrupted	Afferent Paths from Intestine Interrupted	Duration of Distention	Change in Bowel Circulation (color)	Alteration in B.P.	Explanation
1	62 Mm.Hg.	Dog	Yes	No	5 min.	Return from cyanosis to normal	+ 28	
2	80 "	Cat	Yes	No	5 min.	"	+ 50	Increased
3	90 "	Dog	Yes	Yes	2 min.	"	+ 30	
4	90 "	Cat	Yes	Yes	5 min.	"	+102	return of
5	100 "	Dog	Yes	Yes	4 hrs.	"	+ 28	
6	120 "	Dog	Yes	Yes	8 hrs.	"	+ 44	venous
7	90 "	Dog	Yes	Yes	7 hrs.	"	+ 22	
8	80 "	Cat	Yes	Yes	5 hrs.	"	+ 68	blood to
9	Release of ligation of superior mesenteric vein of dog					"	+ 24	heart
10	90 Mm.Hg.	Dog	Yes	Yes	6 hrs.	Return from cyanosis to normal	− 55	? Return of depressor substance
11	90 "	Dog	Yes	Yes	17 hrs.	"	− 78 (death)	in blood from intes-
12	90 "	Dog	Yes	Yes	18 hrs.	"	− 32	tine
13	40 "	Dog	Yes	Yes	12 hrs.	"	− 56	
14	80 "	Dog	No	No	12 hrs.	"	− 23	
15	90 "	Dog	Yes	Yes	21 hrs.	Remained cyanosed	No change	Thrombosis in bowel
16	90 "	Dog	Yes	Yes	17 hrs.	"	"	veins

The fall in blood pressure in these animals occurred even after the complete denervation of the bowel, either by division of the mesenteric nerves or by bilateral excision of the sympathetic trunk and double vagotomy. When the distended intestine is deflated, the distended intestinal veins empty, blood returns from these veins to the general circulation and augments the blood volume, and yet, instead of a rise of blood pressure, there is a fall, which is sometimes progressive over a period of some hours, and which is occasionally fatal. This fall in blood pressure would appear to be due to the passage of toxic depressor material into the blood stream. Toxic material from the lumen has, during distention, diffused into the tissue fluids of the bowel wall, but has failed to enter the blood stream, because of the intestinal congestion which is



Dog. Effect of sudden release (at arrow) of an intraintestinal pressure of 90 mm. maintained for 18 hours.

CHART 6.

present. On the relief of congestion, the tissue fluid, bearing the toxic material which it has acquired during distention, enters the intestinal capillaries and returns with the intestinal blood to the general circulation, to exercise a depressor effect.

Braun and Boruttau recorded an ingenious and dramatic experiment which is of some value in this connection. As I have already mentioned above, Braun and Boruttau found that a lethal dose of strychnine could be injected into an isolated and distended bowel loop in the experimental animal without the appearance of symptoms, provided the intra-intestinal pressure was sufficiently high in the isolated loop. They showed, however, that sudden deflation of the strychnine-containing loop was followed, as a rule, by the immediate appearance of strychnine convulsions, and by the early death of the animal. The effects of sudden deflation of a distended loop containing strychnine were

almost as rapid as the effects of intravenous injection of the drug. Braun and Boruttau explain these experiments in this way: They consider that, during distention, the strychnine passes into the stagnant tissue fluid of the congested wall of the distended bowel, but fails to pass into the blood stream, because of the sluggishness of local circulation in the bowel. As soon as the distention and congestion of the bowel loop are relieved, however, the local circulation recovers, and strychnine is able now to diffuse rapidly from the tissue spaces into the blood stream. It appears likely that, in intestinal obstruction, toxic material from the lumen behaves in the same way. During distention it passes into the tissue spaces of the bowel wall, but succeeds in reaching the blood stream only when the local circulation in the bowel is improved by deflation.

The nature of the toxin which produces a depressor, and sometimes a lethal, effect on the experimental animal after the relief of an obstruction is not known. Blood collected from the portal vein and from the mesenteric veins during deflation of a distended bowel loop has been shown to have sometimes a depressor effect when injected into other animals.[4] It can thus be fairly argued that, while no proof has ever been offered of a true toxemia during intestinal distention, there is considerable evidence that a rapid toxemia may occur soon after the relief of intestinal distention.

One important principle emerges—the immediate relief of an early obstruction is beneficial—a low blood pressure will rise. Sudden release of a long-continued distention of the bowel, with severe intestinal cyanosis, is likely to be followed by a perhaps dangerous fall in blood pressure, and some part of the present (postoperative) mortality of obstruction may be explained by the depressor effect of sudden relief of intestinal distention-congestion.

The results of sudden intestinal deflation are an important argument against aspiration of distended bowel loops at operation, and the milking down of distended bowel to empty it forcibly; Storck and Ochsner[30] have demonstrated how serious a depressor effect such mechanical decompression of the intestine may have on the carotid blood pressure in the experimental animal.

The depressor effect of deflation in the experimental animal may suggest that any form of relief of a long-continued obstruction may not be without danger. The risk of sudden decompression of distended bowel has been particularly stressed by Wheeler,[35] who points out that wherever fluid is present under tension in the body a sudden evacuation of the fluid may have a serious effect; Wheeler advocates that distended bowel in obstruction be decompressed as slowly as the pleural cavity in empyema, or the distended bladder in retention of urine. Our experiments in deflation of bowel strongly support Wheeler's contention. The surgeon who accepts the validity of our argument is on the horns of a dilemma when faced with an acute intestinal obstruction of long standing. On the one hand, he cannot permit obstruction to continue, and on the other, he is aware of the possible risk of sudden release of the obstruction. Time alone will produce a satisfactory solution of this problem. In the meantime, the experiments described strongly support recent suggestions for slow decompression of distended bowel, either by preoperative nasal

suction drainage, as suggested by Wangensteen,[34] or by some form of controlled enterostomy which permits the distending gas to escape, only gradually, over a period of some hours.

Let it be understood, finally, that this demonstration of a toxemia which follows upon the sudden relief of a long-continued intestinal distention can be applied only to the postoperative toxemia of acute intestinal obstruction. There is no evidence that an actual toxemia is present during the presence of an unrelieved intestinal distention. It might be argued that, during distention, a sudden wave of peristalsis passing over the distended bowel might squeeze from it, into the circulation, some of the toxic products which appear to lie within its wall. Peristalsis may perhaps have the same effect during an obstruction as do milking and stripping of the bowel at the time of operation. A theory of an intermittent toxemia due to the entry into the circulation of toxic material from the bowel with each vigorous peristaltic wave must remain a matter of conjecture. The other morbid factors which have been shown to be present throughout the relatively long course of an untreated low small intestine obstruction are sufficient, however, to explain death, and there need be no resort to a hypothetic, intermittent toxemia in these cases.

(3) *Colonic Occlusion.*—Colonic occlusion is particularly well tolerated in experimental animals, and dogs with a complete obstruction of the lower colon may live without symptoms for as long as a month. This is hardly comparable, however, with colonic occlusion as it occurs, typically, in man. The cause in man is usually cancer, and acute obstruction, when it supervenes, occurs only as the culmination of a long-continued, subacute obstruction, as a rule. The bowel has already been dilated, its muscle wall hypertrophied, and the mucosa not infrequently the seat of stercoral ulceration before obstruction becomes complete. Furthermore, the patient is frequently in poor general condition, and sometimes even cachectic. For this reason, colonic occlusion is a more serious form of obstruction in man than it is in the experimental animal. If the occlusion becomes complete, the intracolonic pressure rises to a high level, but the ileocecal sphincter remains competent until a late stage. Ultimately, in most untreated cases, the pressure rises to such a high level within the colon that perforation of its wall occurs, the perforation being situated, as a rule, in a stercoral ulcer of the cecum. In most cases of colonic occlusion, no significant alteration occurs in the blood chlorides, the blood volume, the bicarbonate content, or the blood urea.

B. CLOSED LOOP OBSTRUCTION

Closed loop obstruction has specially lent itself to experimental study, and, as Wilkie first observed, the pathologic course of a closed intestinal loop depends upon the degree to which its contents are infected by bacteria.

(1) *Loops with Sterile Content.*—The best examples of the sterile loop in man are mucocele of the appendix, cyst of the vitello-intestinal duct, and the various enterogenous cysts. As a rule, when a sterile loop of bowel is isolated from the intestinal tract, it dilates gradually with mucus, and no general effects

follow. In the experimental animal, an isolated bowel loop can be effectively sterilized, and, in most cases, after its ends are closed, it dilates, as a similar loop does in man—as a mucocele. In only a few cases does the loop distend so rapidly with mucus that vascular changes occur in its wall, and the animals die after three or four days (Taylor[31]).

(2) *Closed Loops with Heavily Infected Content.*—Wilkie's[36] second form of closed loop obstruction is best seen clinically in obstructive appendicitis. Such a loop contains grossly infected fecal matter, and is closed at both its ends. The organisms within it multiply rapidly, gas accumulates in the lumen, the pressure within the loop rises rapidly, fluids and leukocytes are poured into the lumen, and a pyocele, or empyema, forms. Soon the increase in pressure interferes with the local circulation, organisms enter the devitalized bowel wall, and gangrene, perforation and peritonitis follow. Other things being equal, a small infected loop is more liable to early perforation than is a long one, perhaps because a small loop accommodates itself less easily to a rapid increase in the volume of its content, and more rapidly develops a high pressure within it.

(3) *Closed Loops with Mildly Infected Content.*—Loops of this sort are seen between multiple strictures of the small intestine and in herniae which are obstructed but not yet strangulated. In the clinical case in man, a closed loop is always complicated by a simple bowel occlusion above it, but in the experimental animal closed loops can be prepared without a complicating occlusion. The closed loop is in that case short-circuited by anastomosis, and is sometimes employed in the study of the so-called "toxemia" of obstruction. The closed loop distends in the course of a few days with foul gas and with dark-brown, blood stained fluid, whose constituents include intestinal juice, leukocytes, fragments of dead epithelium, whole blood and bacteria. The intraloop tension reaches an enormous level, sometimes as high as 70 cm. of water, because the closed loop cannot relieve the pressure within it by evacuation of some part of its content upwards, as the distended bowel above a simple occlusion can. The intra-intestinal pressure within a closed loop rises more rapidly and to a higher level than does the pressure in the bowel loops above a simple occlusion. The walls of the loop are tense and congested and edematous, with bacterial invasion and leukocyte infiltration. The mucosa is necrotic and ulcerated, as a result of the high tension within the loop, and cyanosis is soon obvious in it. The muscle coat is flabby and inflamed, and the serosa is usually congested. The terminal changes in the bowel wall are sometimes very similar to the changes of strangulation.

A loop of this kind closely resembles the lowest distended loop above a simple low intestine occlusion, and it is difficult not to believe that the cause of death is similar in both these conditions. There are certain modifying factors, however, in the course of a closed loop: Perforation and peritonitis, while not necessarily present before death, are rather more frequent in the closed loops than in cases of simple occlusion. Where death occurs without perforation and peritonitis, the closed loop will usually be found in a state of gross conges-

tion, and reference to Table III will demonstrate that the blood and fluid lost into the wall of a long, closed loop may amount to as much as one-third of the total blood volume. So great, indeed, may be the congestion of the loop that at the time of death it may be considered to be in a state of strangulation, not from occlusion of its mesenteric vessels, but from closure of the vessels in the wall of the loop itself, as a result of the enormous intraloop pressure. The relatively common incidence of perforation and peritonitis, the increased degree of blood loss from the general circulation, and the occurrence of actual devitalization in the wall of the distended bowel are three factors which explain why the course of closed loop obstruction is so much more rapid than the course of simple occlusion of the bowel.

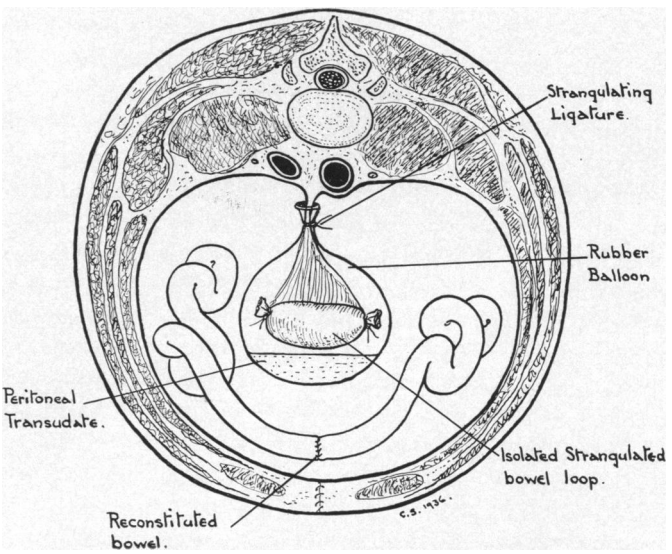


FIG. 1.—Showing the method of determining blood loss following strangulation (Foster and Hausler). An isolated bowel loop is placed in a rubber bag, and strangulated by a ligature tied around the neck of the bag. The intestinal lumen is reconstituted around the isolated loop by anastomosis.

It should be remembered that sudden deflation of a closed loop may exercise the same toxic effect as sudden relief of a simple occlusion or a strangulation.

C. INTESTINAL STRANGULATION

Pure forms of intestinal strangulation are rare clinically. In strangulation by hernia, for example, or by a band, a simple occlusion is present usually above the strangulated loop, but the effects of strangulation are so rapid, as compared with the effects of simple occlusion, that the strangulation element always outweighs in importance the occlusive element. Strangulation is seen in a pure form in mesenteric embolism and thrombosis.

It is convenient to consider strangulation under three heads, since the predominant lethal factor appears to vary according as a strangulated loop is very short, very long, or of medium size.

(1) *Short Loop Strangulation.*—This form is exemplified clinically by the small, nonviable patch of bowel wall which, on occasion, may occur in a Richter's hernia, or at the apex of a reduced intussusception. It is also seen clinically in the late obstructed appendix when circulation has ceased in the vessels of the appendix wall. In strangulation of a short loop, death is due, as a rule, to gangrene, rupture and peritonitis.

(2) *Long Loop Strangulation.*—Long loop strangulation is clinically exemplified by mesenteric thrombosis and embolism, and the picture of the patient suffering from occlusion of the superior mesenteric artery or vein is characteristic. The sudden pain at the onset of the disease is followed rapidly by a progressive pallor, increase in pulse rate, and fall in blood pressure. An enormous volume of blood is lost into the bowel lumen, into the peritoneal cavity, and into the congested wall of the bowel itself, and the patient dies after a few hours just as he would die from a massive internal hemorrhage. The amount of blood lost by the experimental animal in an extensive strangulation has been measured by Holt[19] and by Scott and Wangensteen.[27] The strangulated loop is surrounded by a rubber bag (Fig. 1), and the amount of blood lost is the sum of the blood in the lumen of the bowel, the blood in the rubber bag around it, and the blood lying in the congested vessels and tissue spaces of the bowel wall itself. The actual amount of blood lost into the lumen and the rubber bag is estimated by the measurement of the hemoglobin content of the fluid in these two situations. The blood lost into the intestinal wall is measured by the increase in weight of the strangulated loop at the time of death. Scott and Wangensteen decided from their experiments that 66 per cent of the total blood volume could be lost in this way. Holt,[19] using a similar technic, estimated the blood loss at 50 per cent in certain cases, and my experiments support these statistics. The estimations of blood loss obtained in my rubber bag experiments[6] are shown in Table VI.

It has been argued that the rubber bag technic, which was first introduced by Foster and Hausler,[17] gives a false estimate of the amount of blood lost in this condition, since, in strangulation in man, a proportion of the lost volume is reabsorbed by the peritoneum. I have attempted to measure the blood volume directly, however, in animals suffering from massive strangulation,[7] and have found that the diminution of blood volume after the production of massive strangulation is dramatic (Table VII). When the whole small intestine of an animal is strangulated, there is a reduction of approximately 50 per cent in the blood volume of the animal when death occurs a few hours after the strangulation is induced. The reduction affects the cell volume to a much greater extent than the plasma volume, since, even during the short period of progressive blood loss, an attempt is made to maintain the blood volume by the passage of tissue fluids into the circulation (Chart 7). The effect of massive venous strangulation on blood volume is precisely similar to the effect of a rapid hemorrhage. The clinical application of these experiments is important. The patient suffering from massive strangulation requires blood transfusion, and not the introduction of a mere pint of blood, but the addition from donors

TABLE VI

SHOWING THE AMOUNT OF BLOOD APPARENTLY LOST INTO A STRANGULATED LOOP SURROUNDED BY A RUBBER BALLOON

The loss of one-third of the blood volume by hemorrhage is serious, and loss of one-half of the blood volume by hemorrhage is likely to be fatal. (By permission of the Edinburgh Medical Journal)

No. of Exper.	Fraction of Jejuno-Ileum Strangulated	Weight of Balloon plus Content (Gm.)	Weight of Balloon plus Normal Loop of Equal Length (Gm.)	Weight of Blood Lost (Gm.)	Estimated Blood Volume (Cc.)	Blood Loss as Percentage of Whole Blood Volume	Duration of Life
1	One-half.....	170	60	110	210	52	Died in 24 hrs.
2	One-half.....	220	140	80	188	43	Died in 24 hrs.
3	Two-sevenths.	132	90	42	120	35	Killed after 18 hrs.
4	One-quarter..	193	154	39	172	23	Killed after 24 hrs.
5	Two-ninths...	184	142	42	158	27	Killed after 18 hrs.
6	Two-ninths...	160	107	53	165	32	Killed after 18 hrs.
7	One-fifth.....	142	111	31	135	23	Killed after 18 hrs.
8	One-fifth.....	203	151	52	188	28	Killed after 24 hrs.
9	One-seventh..	173	140	33	150	22	Died after 20 hrs.

TABLE VII

VENOUS STRANGULATION

EFFECT OF STRANGULATION ON THE BLOOD VOLUME, PLASMA VOLUME AND CELL VOLUME

It will be seen that in the longer strangulations the blood volume may be reduced to approximately one-half of its normal level. The cell volume is proportionately more reduced in most cases than the blood volume, as there is an attempt at replacement of the lost blood by the passage of tissue fluids into the circulation, just as after a rapid hemorrhage. In short strangulations, the plasma loss exceeds the blood loss; these animals live for a relatively long period, and suffer severely from vomiting before death.

No. of Exper.	Amount of Small Intestine Strangulated	Duration of Life	Mean Blood Volume (Cc.)	No. of Preoperative Readings	Reduction in Blood Volume	Reduction in Plasma Volume	Reduction in Cell Volume
1	Whole length.....	7¼ hrs.	870 ± 16%	9	44%	37%	47%
2	Whole length.....	2½ hrs.	430 ± 8%	9	52%	50%	59%
3	One-third.....	12 hrs.	740 ± 9%	7	30%	16%	50%
4	One-third.....	5 hrs.	1,170 ± 10%	5	49%	30%	66%
5	One-fifth	5 hrs.	1,240 ± 4%	10	40%	30%	55%
6	One-third.....	5½ hrs.	1,480 ± 7%	7	43%	27%	68%
7	One-tenth (approx.).	24 hrs.	1,060 ± 9%	5	17%	30%	8%
8	One-twentieth (approx.).....	4 days	2,150 ± 2%	5	15%	21%	10%
9	One-fortieth (approx.).....	12 days	1,570 ± 11%	8	Nil	Nil	Nil

of an amount of blood equivalent to almost one-half of the patient's blood volume. Massive strangulation, extensive mesenteric thrombosis, for example,

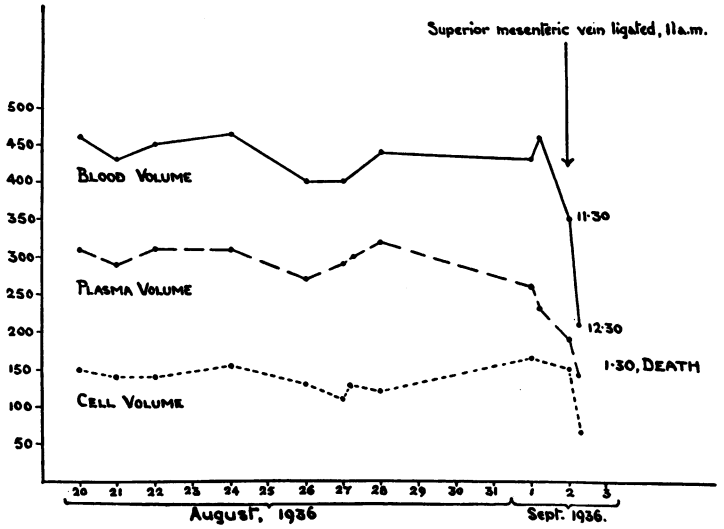


Chart 7.—Dog. Weight 6.8 Kg. Massive venous strangulation: Death in two and one-half hours. Blood volume reduced by 52 per cent, cell volume by 59 per cent, at time of death. (By permission of the British Journal of Surgery)

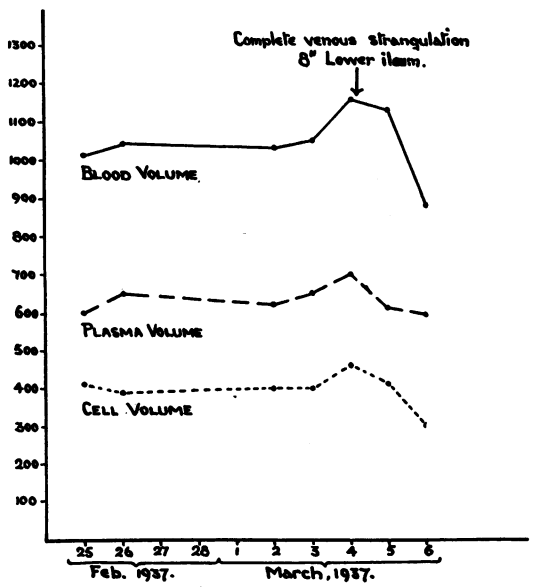


Chart 8.—Dog. Weight 17.5 Kg. Medium loop strangulation: Slight terminal reduction in blood volume, insufficient to be responsible for death. (By permission of the British Journal of Surgery)

requires massive transfusion, and operation is justifiable only after the blood volume has been restored to an approximately normal level.

(3) *Strangulation of Loops of Medium Length.*—Blood loss from the general circulation, while sometimes considerable in this form of strangulation, is not sufficiently great to account for death. The effect on the blood volume is not, as a rule, remarkable. In an animal suffering from strangulation of one-fortieth of its small intestine, there was no alteration in the blood volume, in the plasma volume, or the cell volume, at the time of death. In an animal with one-twentieth of the small intestine strangulated, there was a 15 per cent reduction in blood volume; in an animal with one-tenth of its small intestine strangulated a reduction of 17 per cent in the blood volume at the time of death (Chart 8), and the cell reduction in these cases was inconsiderable, the great part of the depletion of blood volume being due to a loss of plasma (Table VII).

Foster and Hausler[17] first showed that the cause of death in medium loop strangulation is the absorption by the peritoneum of toxic material which has its origin in the strangulated loop. If a loop of small intestine of medium length is isolated, and intestinal continuity reestablished by anastomosis, and if the isolated loop is now surrounded by a rubber bag and strangulated by a ligature tied around the neck of the bag where it encircles the mesentery of the isolated loop, the experimental animal may survive indefinitely (Fig. 1). Foster and Hausler showed, further, that the blood stained transudate which collects in the rubber bag, and which, in the absence of the bag, would be absorbed by the peritoneum, has a toxic effect when injected into other animals. Holt[19] also made an extensive study of the toxicity of the peritoneal transudate from strangulated loops of medium length, and came to the conclusion that two separate toxic elements were present—one which passed outwards from the loop almost immediately after the establishment of strangulation, and which he considered a product of abnormal tissue metabolism; the other a late addition to the transudate, and apparently bacterial in origin. If a chemical fractionation is performed of the transudate collected in one of Foster and Hausler's rubber bags, it is found that two of the chemical constituents of the transudate appear to exercise a toxic effect. One of these is contained in the diffusible fraction of the transudate, while the other is precipitated with the euglobulins. The transudate exercises a considerable depressor effect on the blood pressure when injected intravenously in any anesthetized animal, and attempts have been made to identify the depressor substance concerned.[3, 9, 19, 23, 33] Early measurements of the histamine content of the transudate by biologic assay suggested that a high proportion of histamine was present in the transudate from strangulated loops, and the total histamine content of the transudate from an eight-inch strangulated loop in a cat was considered then to amount to as much as 4 mg. in some cases. High as this concentration appeared to be, it did not entitle histamine to be regarded as the sole lethal factor, or, indeed, as an important lethal factor, in intestinal strangulation, for the gradual absorption by the peritoneal cavity of 4 mg. over a period of 24 hours would exercise no effect on the animal concerned. Maycock,[23] with a more recent technic of histamine assay, estimated the histamine content of the fluid collected from nonviable strangulated loops to be from 0.3

to 2.0 gamma per cc., with a maximum total of one-sixth of a milligram in the whole amount of fluid collected; he further estimated the choline percentage at from 8 to 75 gamma per cc. of fluid. Maycock concluded that these amounts of histamine and of choline were sufficient to explain the depressor effect of the peritoneal fluid collected from strangulated intestine, but were not sufficient to account for death in that condition. He tended to minimize the importance of a toxic element in the peritoneal transudate. He found that the slow intravenous infusion of peritoneal transudate into normal anesthetized animals has usually no depressor effect upon the blood pressure, although in six out of ten of Maycock's experiments the animal into which the transudate was poured died. Maycock was disinclined to believe that the toxicity of the peritoneal transudate, even in association with the serious depletion of blood volume which sometimes occurs in these animals, was responsible for death in intestinal strangulation. His grounds for this view were that in ten cats, in whom strangulation transudate was injected intraperitoneally after removal of from 51 to 73 cc. of blood, only three cats died, and the remaining cats appeared to be unaffected. It seems clear from Maycock's experiments that the histamine and choline content of peritoneal fluid is not of sufficient amount to be an important lethal factor in strangulation, yet the toxicity of this fluid is well established, and appears to lie, as I have said, partly in the diffusible fraction, partly in the euglobulin fraction of the transudate.

The toxicity of the transudate appears to depend upon the presence of bacteria within the strangulated loops. Closed loops of dead sterile bowel taken from newborn guinea-pigs, a few hours after birth, and transplanted into the peritoneal cavities of other animals, disappear without trace and without injury to the host (Table VIII). Dead, closed loops from older guinea-pigs, similarly transplanted, contain both aerobic and anaerobic organisms, and lead to the death of their hosts within a few hours, without peritonitis. The recipient animals die in these circumstances because of the nonviability of the transplanted loop, in combination with the bacteria which it contains.[4]

TABLE VIII

EFFECT OF TRANSPLANTATION OF BOWEL FROM NEWBORN GUINEA-PIG INTO CAT

In Expers. 1, 2 and 3, the transplanted small intestine is sterile, and disappears in the peritoneal cavity of the host without trace and without effect. In Expers. 4 and 5, the host died—without peritonitis, but apparently from the absorption of toxins from the dead transplanted and infected loop of older guinea-pigs.

No. of Exper.	Age of Guinea-Pig Donor	Culture of Content of Guinea-Pig Bowel	Effect of Transplant on Cat Host
1	8 hrs.	Sterile	No ill effects: Indefinite survival
2	32 hrs.	Sterile	No ill effects: Indefinite survival
3	56 hrs.	Sterile	No ill effects: Indefinite survival
4	72 hrs.	Aerobes and anaerobes	Died 24 hrs. Transplanted bowel distended. No peritonitis
5	96 hrs.	Aerobes and anaerobes	Died 20 hrs. Transplanted bowel distended. No peritonitis

TABLE IX

RELATION OF BACTERIA TO THE TOXICITY OF THE PERITONEAL TRANSUDATE IN STRANGULATION

Development of toxicity in peritoneal transudate from strangulated loops. Transudate from early strangulations is nontoxic; and the seromuscular coat from the strangulated bowel in these is sterile. Transudate from later strangulated loops is toxic, and the outer coats of the strangulated bowel, though not necessarily the transudate itself, are infected.

Length of Bowel Strangulated	Length of Survival Period	Results of Intraperitoneal Injection of Balloon Fluid	Cultures of Seromuscular Coat	Cultures of Balloon Fluid
Whole small intestine	Died in 6 hrs.	Whole amount nontoxic to guinea-pig	Sterile	Sterile
1 foot ileum	Killed in 8 hrs.	"	Sterile	Sterile
1 foot jejunum	Killed in 10 hrs.	"	Sterile	Sterile
1 foot ileum	Killed in 12 hrs.	"	Sterile	Sterile
1 foot jejunum	Killed in 15 hrs.	"	Sterile	Sterile
1 foot ileum	Killed in 18 hrs.	"	Sterile	Sterile
1 foot jejunum	Killed in 18 hrs.	"	Sterile	Sterile
1 foot ileum	Killed in 18 hrs.	"	Sterile	Sterile
2½ feet jejunoileum	Died in 24 hrs.	"	Sterile	Sterile
1 foot jejunum	Killed in 30 hrs.	Whole amount killed cat in 8 hrs. [1, 2, 3, 5]	Aerobes and anaerobes	Aerobes and anaerobes
1 foot ileum	Killed in 18 hrs.	5 cc. killed g.-p. in 8 hrs.[1, 2, 3, 4] 2 cc. killed mouse in 2 hrs.	Aerobes and anaerobes	Sterile
2½ feet jejunoileum	Died in 24 hrs.	2 cc. killed g.-p. in 4 hrs.[1]	Aerobes and anaerobes	Aerobes and anaerobes
1 foot ileum	Killed in 24 hrs.	5 cc. killed g.-p. in 7 hrs. [1, 2, 3]	Aerobes and anaerobes	Aerobes and anaerobes
9 inches ileum	Died in 20 hrs.	5 cc. killed g.-p. in 6 hrs.[1, 2, 5] 2 cc. killed mouse in 2 hrs.	Aerobes and anaerobes	Aerobes and anaerobes
1 foot ileum	Killed in 24 hrs.	5 cc. killed g.-p. in 8 hrs.[1, 2, 3, 4]	Aerobes and anaerobes	Aerobes and anaerobes
1 foot ileum	Killed in 20 hrs.	5 cc. killed g.-p. in 6 hrs.[1, 2]	Aerobes and anaerobes	Sterile
1 foot ileum	Killed in 27 hrs.	4 cc. killed g.-p. in 5 hrs.[1, 3, 4, 6]	Aerobes and anaerobes	Aerobes and anaerobes

Symptoms in Injected Animals:

[1] Apathy, weakness, increased respiratory rate before death. At autopsy no peritonitis.

[2] Autopsy showed marked congestion of liver and spleen.

[3] Spastic seizure of hind limbs before death.

[4] Intense respiratory embarrassment before death. Autopsy showed emphysema.

[5] Velvety red congestion of duodenum and upper jejunum.

[6] Autopsy showed subendocardial hemorrhages.

The importance of bacteria in strangulation is further demonstrated by the fact that in the earlier stages of strangulation, when the peritoneal transudate has not yet become toxic, the outer layers of the wall of the strangulated bowel are sterile, as is, also, the peritoneal transudate itself. This can be easily

shown by the strangulation of bowel loops in rubber bags, if, at the time the fluid is collected, a biopsy specimen be obtained, with sterile precautions, from the seromuscular coat of the bowel, without opening the lumen (Table IX). If the fluid has become toxic, the seromuscular coat of the bowel gives a growth of aerobes and anaerobes in every case. In most, but not in all, of these later strangulations, the peritoneal transudate itself also gives a growth of organisms. The conclusion is inescapable that death in medium loop strangulation is due to infection of the devitalized bowel by bacteria from its lumen, and to the absorption by the peritoneum of the toxic products of their growth. It seems likely that the toxic euglobulin fraction of the peritoneal transudate contains the actual toxins of the bacteria, while the toxic diffusible fraction of the transudate contains the by-products of tissue destruction.

Knight[21] has shown that depressor substances are present in human cases of strangulation, not only in the peritoneal fluid, but in the blood within the veins of the strangulated segment of intestine. Knight and Slome[20] have further demonstrated that, in cases of strangulation, while the affected bowel loop still remains viable, a toxic effect is demonstrable in fluid obtained from the thoracic duct. In clinical cases of strangulation in man, it seems likely that death is due to a complex combination of pathologic factors, which include: (1) Diminution of effective circulating blood volume, in some cases at least, by loss of blood into the lumen of the strangulated bowel, into the bowel wall, and into the peritoneal cavity; (2) absorption of toxic transudate by the peritoneal cavity; (3) absorption of toxic material from the tissue spaces of the affected segment of bowel by lymphatic paths until these become closed as a result of circulatory stasis. It is common knowledge that a strangulated external hernia is a much less serious condition than strangulation of a bowel loop within the peritoneal cavity. This is almost sufficient clinical proof of the importance of peritoneal absorption of the toxic transudate. The sac of a hernia is capable of only slight absorption of the transudate from the strangulated loop which it contains.

Mention has been made in an earlier part of this paper of the depressor effect which sometimes follows relief of a simple occlusion of the bowel. An even more marked depressor effect occurs, in many cases, after relief of a still viable strangulation. Knight found, in animal experiments, that release of viable strangulations produced circulatory collapse and death in not less than 15 per cent of the animals used.[21] Here again, it would appear that during early strangulation, and the venous congestion which it produces, toxic materials from the lumen succeed in diffusing into the tissue fluids of the wall of the strangulated bowel, but fail to enter the general circulation, because of venous obstruction. When, however, the strangulation is relieved, the veins of the affected segment of bowel empty, circulation returns, and the toxin-laden fluid within the wall of the strangulated bowel can now reach the general circulation, to exercise a toxic, and sometimes lethal, effect. In fatal cases of strangulation in man, operation has nearly always been performed. At operation, the strangulated loops of bowel are closely inspected for signs of non-

viability. If the bowel appears to be viable, even though still congested, it is returned to the abdomen, and gradually, thereafter, recovers its normal circulation. It has long been known that whenever there is any doubt about the viability of a strangulated loop, it can be returned to the abdomen, as a rule, without any risk of gangrene and peritonitis. I would submit that the main risk in returning a strangulated loop to the abdomen is not the risk of perforation of that loop, but the danger that, in recovering its viability, there may be a return of toxic material from the wall of the strangulated bowel. This is a strong argument in favor of the more frequent resection, or, at least, exteriorization, of strangulated intestinal loops. "All recent experimental work has gone to show that when the least doubt exists as to the viability of the bowel, resection should be practiced, as continued toxemia from autolysis of cells and potential obstruction from imperfect peristalsis may lead to death some days after operation" (Wilkie[36]).

CONCLUSIONS

In high small intestine occlusion, the cause of death is dehydration, hypochloremia, alkalemia, and azotemia. These can be effectively controlled by nasal suction drainage and forced intravenous saline by drip. Operation may be delayed, and conservative measures continued for many days before operative relief of the obstruction, provided the cause of obstruction is known, and provided the presence of a strangulating element can be definitely excluded.

In untreated cases of low small intestine occlusion, whether in the experimental animal or in man, death does not occur, as a rule, until three or even four weeks after the onset of obstruction. In these cases, suspended absorption of water, salts, food materials, and other constituents of the intestinal content is sufficient to explain death. Gross congestion of the bowel is sometimes considerable before death in these cases, and leads in some, but not in all, animals to depletion of the blood volume. Perforation of the distended bowel and peritonitis is a relatively frequent cause of death in the animal or man whose occlusion remains unrelieved by operation.

To-day, the deaths from low small intestine occlusion are nearly all postoperative deaths. The toxic effect of sudden relief of a long-continued distention of the bowel has been demonstrated by experiment.

In occlusion of the colon, perforation and peritonitis are responsible for death in most cases. In long-continued colonic occlusion, the same factors probably operate as operate in low small intestine obstruction.

In closed loop obstruction, the cause of death depends upon the infectivity of the contents of the loop. In the case of the heavily infected closed loop, death is due to perforation and peritonitis. In the mildly infected closed loop, the same morbid influences are present as in low small intestine occlusion. Splanchnic congestion is usually more serious in closed loop than in simple occlusion.

In strangulation of short loops of bowel, death is due to perforation and peritonitis.

In long loop strangulation, death is due to diminution of the effective circulating blood volume, as a result of blood loss into the lumen and wall of the strangulated intestine, and into the peritoneal cavity.

In strangulation of loops of medium length, the cause of death appears to be the absorption of toxins. In the early stages of strangulation, this is by way of lymphatic routes, later by way of the peritoneal cavity.

The depressor effect of the sudden relief of any form of intestinal distention is seen in an exaggerated form upon the sudden relief of a long-continued strangulation.

A method is described of the establishment of chylothorax in the experimental animal, to furnish reservoirs of chyle for the purpose of experimental chyle transfusion.

The later experiments recorded in this paper have been performed in the Department of Surgery of the University of Edinburgh, under the direction of the late Sir David Wilkie, and of the Deputy Director, Mr. W. C. Wilson, now Regius Professor of Surgery in the University of Aberdeen. Many of the earlier experiments were performed in the Department of Surgery of Washington University, St. Louis, under the direction of Dr. Evarts A. Graham, and with the guidance of Dr. Robert Elman. The American experiments were performed during the tenure of a Rockefeller Traveling Scholarship, and the later part of the work in Scotland has been subsidized by a grant from the British Medical Research Council.

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